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50. Internationales Wissenschaftliches Kolloquium
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Dr. László Molnár /János Halas / László Valenta

Measurement by strain gauges and FEM simulation in industrial applications

ABSTRACT

In this paper the real time mechanical stress measurement of a 3000 ton press machine and the FEM analysis will be demonstrated and compared. The reason to examine the tympan sheet of the press machine was the well visible splits arising at the “T” notches of the lower plate. The positions of the strain gauges were determined by these splits.

Previous to the measurements the reparation of the plate was made. The used technology was to grave the environment of the splits, to warm up to 150°C, to weld up the holes, to upset the welds and to whet. The cooling was controlled.

At the end of this paper the results of the FEM simulation of this plate will be demonstrated and compared to the measurement.

THE MEASUREMENT TASK

The primary reason of the measurement was to find out the maximal mechanical stress at the environments of the “T” notches in the function of the process stage. Another task was to show the weakening effect of the corners.

The requirement was to measure simultaneously in 14 points, and to register them in a computer. To know the process phase to get one more analogous sign in the computer was needed which was proportional to the position of the tympan sheet.

THE MEASURING POINTS

There were four “T” notches on the front and the back side of the tympan sheet too. The splits arrived on both of the sides the back side was chosen because of safety considerations and easiness of measuring. Four measuring environments were chosen, according to Fig. 1. The V. measuring environment was chosen for a reference measurement.

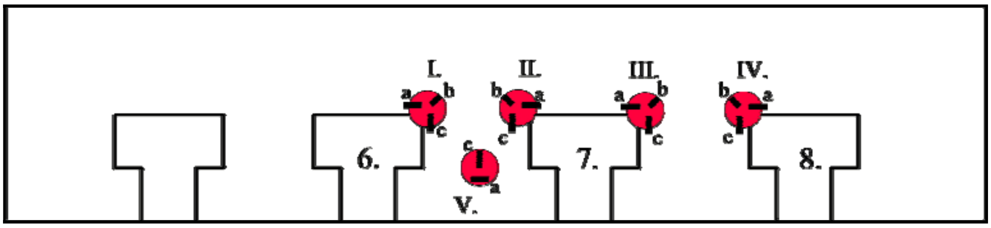

Fig. 1. The measuring points

The next pictures (Fig.2. and Fig. 3.) were taken on the scene the real position of the strain gauges can be seen on them.

Fig. 2. The II. and III. measuring places

Fig. 2. The IV. measuring place

According to the above 2 pictures that is obvious exact simulation of the mechanical stress is not possible because of the geometrical deviations. The surfaces are damaged and the material of the tympan sheet is not homogenous due to the several reparations.

THE AMPLIFIER CIRCUIT

The main requirement was to real time measure the arriving mechanical stress at all places during the pressing cycle. That means a fourteen channel measuring amplifier was needed. We did not have this instrument so a unique amplifier was designed and made for this problem (Fig. 4.).

Furthermore there were no possibilities to make the measurement in full or half bridge mode. We had also no choice to bond thermal compensation gauges on the tympan sheet because the main directions of the mechanical stress were not known before the measurement. Fortunately the thermal compensation was not important in our case because at normal working environment the temperature of the tympan sheet is about 60°C and can be considered to constant because of the large mass. According to the above mentioned a quarter bridge measurement was chosen.

The amplifier circuit was based on single chip instrumentation amplifier from Analog Devices. This amplifier chip (AD623) is capable to make a very large gain (1000x) with large CMRR and small noise.

At the first trying measurements – were not made at the scene – a very high electrical noise has arrived on the measuring wires. The reason of this was the very large distances, the long, approximately 8 meters of wires. To avoid this problem the shielding was driven with low impedance.

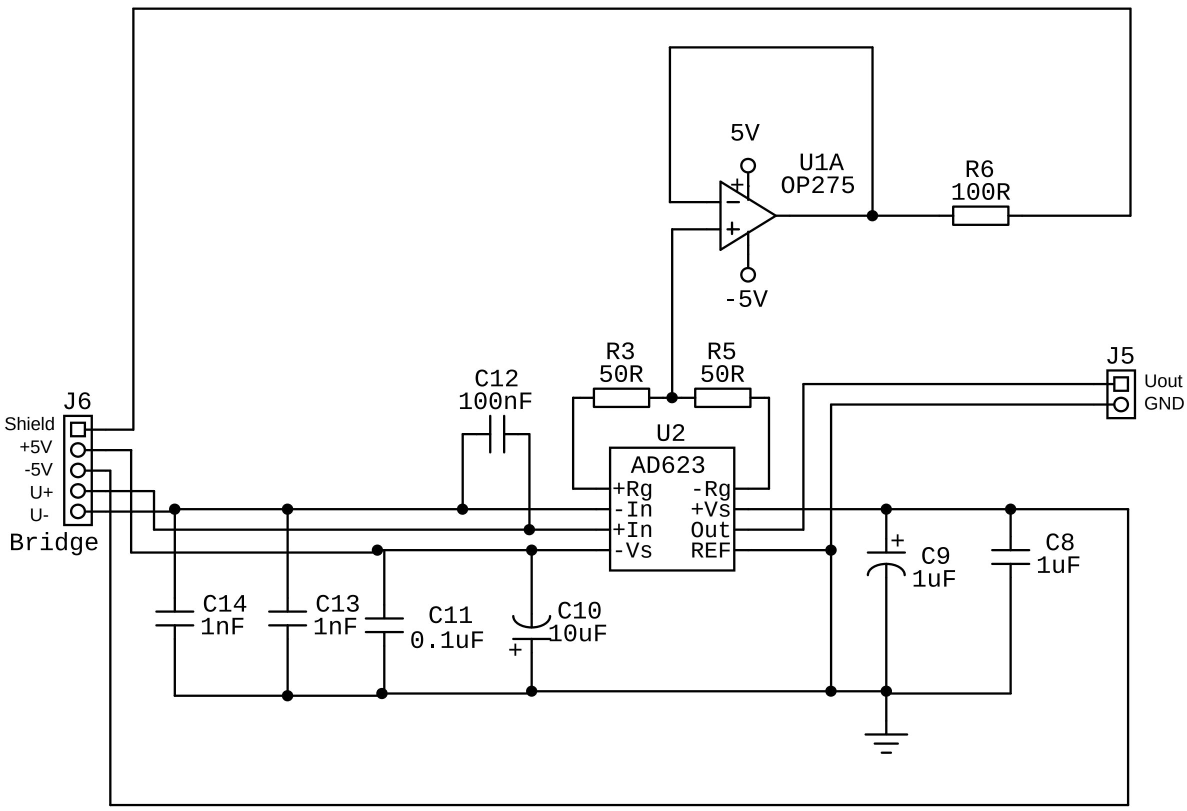

Fig. 4. Schematic of the amplifier circuit

EVALUATION OF THE MEASUREMENT

The resistivity change of each strain gauge was measured simultaneously and collected real time with a personal computer and a DAQ board. With the above amplifier circuit the measuring arrangement is shown on Fig. 5.

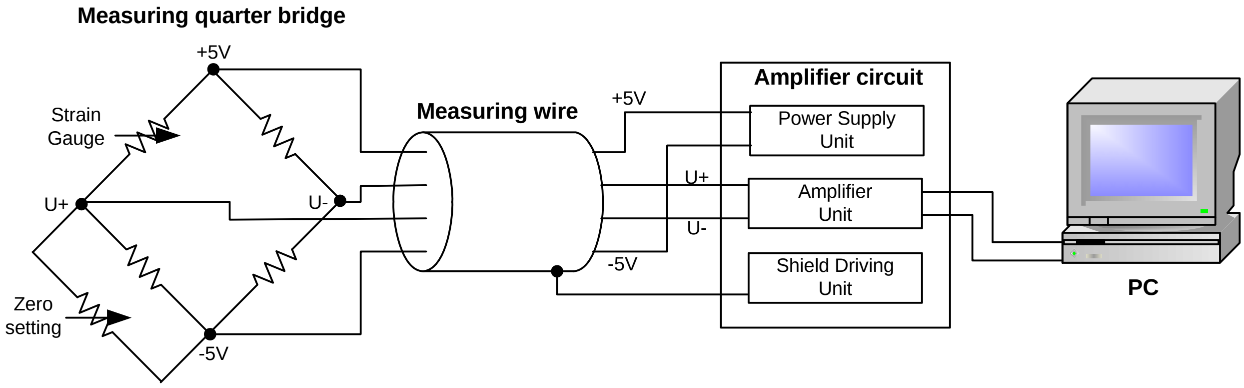

Fig. 5. Measuring arrangement

From the data of the measurement the Huber-Mises-Henky equivalent stress was calculated by the following steps:

The relative strain of the strain gauge can be calculated as:

$$\varepsilon = \frac{4 \cdot U_{ki}}{1000 \cdot g \cdot U_{hid}} \qquad \text{(Eq. 1.)}$$

The main strain expressed by the *"a"*, *"b"*, and *"c"* directions, according to Fig. 6.

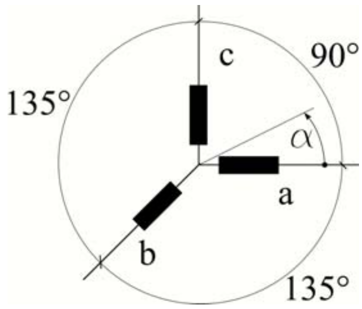

Fig. 6. The directions of the strain gauges

$$\varepsilon_1 = \frac{\varepsilon_a + \varepsilon_c}{2} + \frac{\sqrt{2}}{2} \cdot \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_c - \varepsilon_b)^2} \qquad \text{(Eq. 2.)}$$

$$\varepsilon_2 = \frac{\varepsilon_a + \varepsilon_c}{2} - \frac{\sqrt{2}}{2} \cdot \sqrt{(\varepsilon_a - \varepsilon_b)^2 + (\varepsilon_c - \varepsilon_b)^2} \qquad \text{(Eq. 3.)}$$

The main stresses:

$$\sigma_1 = \frac{E}{1 - \nu^2} \cdot (\varepsilon_1 + \nu \cdot \varepsilon_2) \qquad \text{(Eq. 4.)}$$

$$\sigma_2 = \frac{E}{1 - \nu^2} \cdot (\varepsilon_2 + \nu \cdot \varepsilon_1) \qquad \text{(Eq. 5.)}$$

The angle between the first main direction and the *"a"* gauge:

$$\alpha = \frac{\mathrm{arctg}\left(\frac{2 \cdot \varepsilon_b - \varepsilon_a - \varepsilon_c}{\varepsilon_a - \varepsilon_c}\right)}{2} \quad \text{(Eq. 6.)}$$

And finally the equivalent (HMH) stress:

$$\sigma_{egy} = \sqrt{\sigma_1^{\,2} - \sigma_1 \cdot \sigma_2 + \sigma_2^{\,2}} \quad \text{(Eq. 7.)}$$

The data of the measurements showed 1-2% deviation so it was enough to process the data from only one cycle. The maximal equivalent stresses at four places are demonstrated on Table 1. in the calculation the real material properties (for 52D steel) was taken into consideration.

Position	**Max. equiv. stress [MPa]**
I.	246.68
II.	153.18
III.	192.36
IV.	**293.55**

Table 1. Maximal equivalent stresses

The following diagram shows the calculated equivalent stress in the function of the displacement of the tympan sheet:

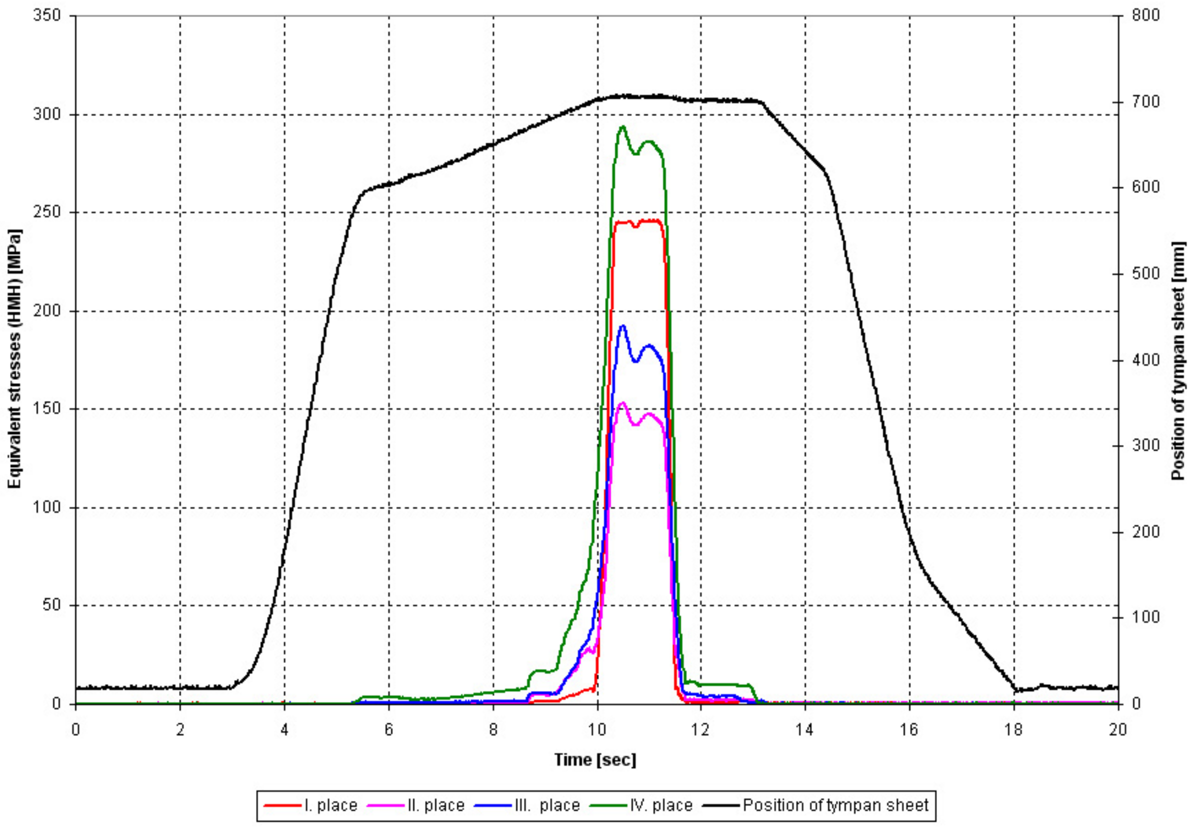

Diagram 1. The equivalent stress vs. the position of tympan sheet

COMPARISON THE FEM SIMULATION WITH THE MEASUREMENT

Like it was mentioned in the introduction an FEM simulation was made on the problem too. In this few rows the results of the simulation and the measurement will be shown. The results of the solution of the FEA are shown on Fig.7 and Fig. 8.

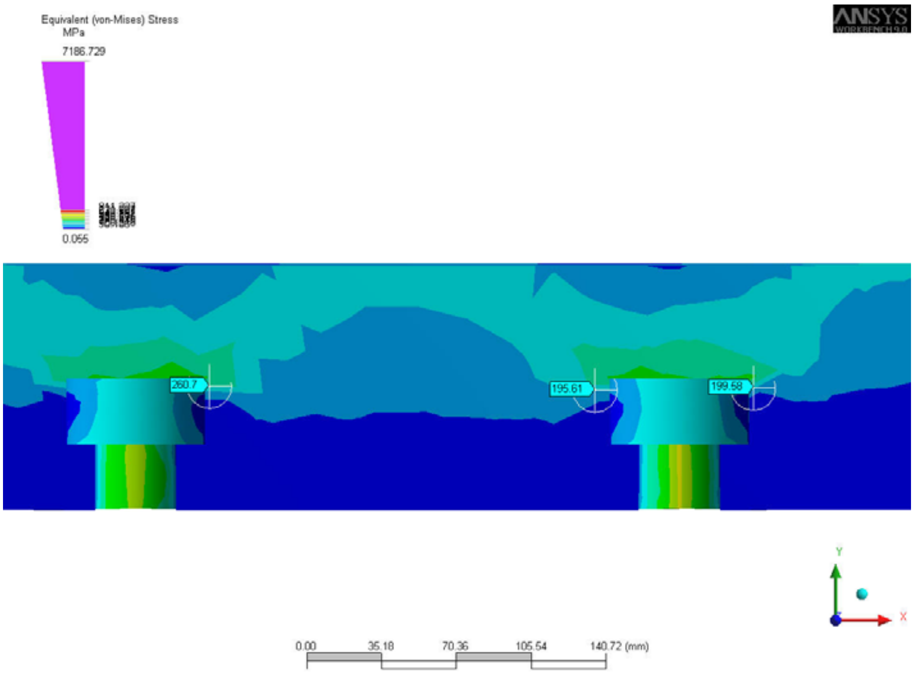

Fig. 7. the Equivalent stress

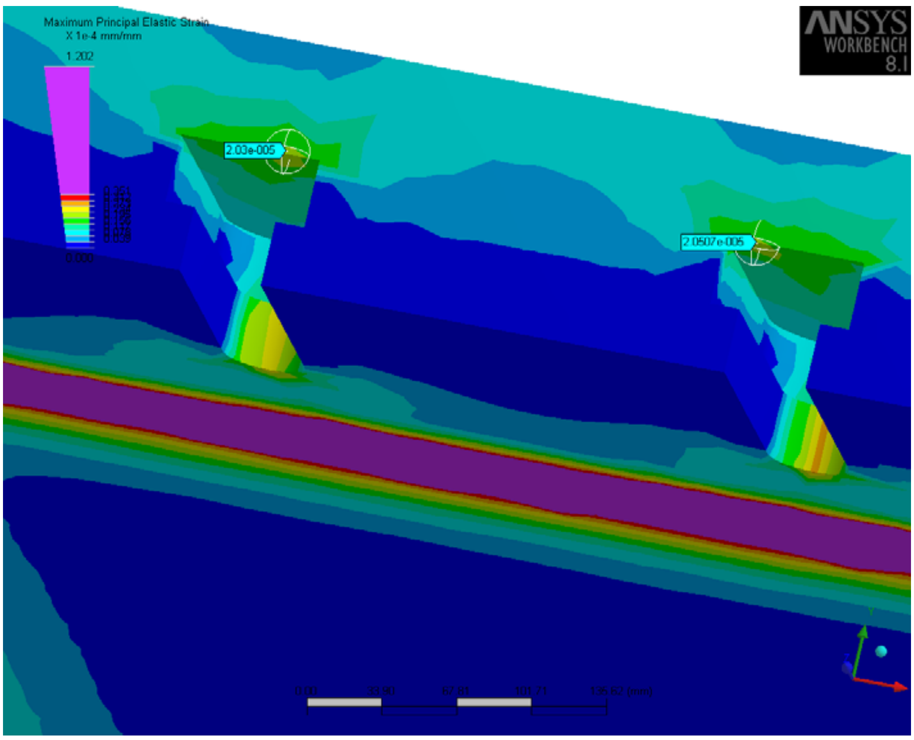

Fig. 8. Maximal elongation in the main direction

As it seen on the above figures there is a small difference between the simulation and the measurement. The reason of this can be the geometrical differences between the real and modeled geometry and the changes of the material properties during the reparation. But it is obvious too the result of the simulation is near to the measurement.

CONCLUSION

The main goal of our project was to find out the basic causes of the splits. The results of the measurement and the results of the simulation also shows that the tympan sheet is loaded by too large pressure. In this project it is also demonstrated the FEM is well usable in real problems, but requires high circumspection.

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